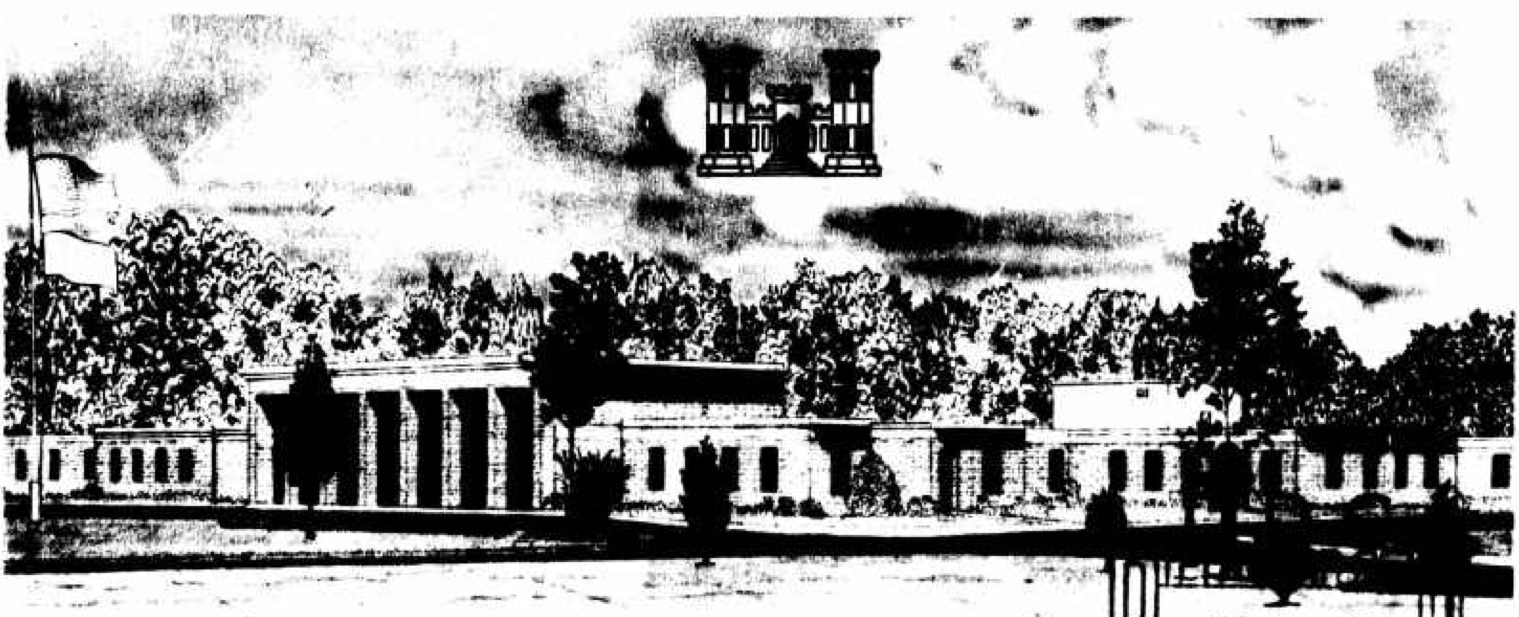
MISCELLANEOUS PAPER S-70-14

EVALUATION OF SOIL STRENGTH OF UNSURFACED FORWARD-AREA AIRFIELDS BY USE OF GROUND VEHICLES

by

G. M. Hammitt II



May 1970

Sponsored by Office, Chief of Engineers, U. S. Army

Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

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ARMY-MRC VICKSBURG, MISS.

Foreword

This study was authorized by the Office, Chief of Engineers, in "Instructions and Outline for Technical Support - Army, FY 1967," dated May 1966. The Flexible Pavement Branch, Soils Division, U. S. Army Engineer Waterways Experiment Station (WES), conducted this study for the Civil Engineering Branch, Engineering Division, Military Construction, Office, Chief of Engineers.

This study was conducted during the period September-November 1967 under the supervision of Messrs. W. J. Turnbull, Chief, and A. A. Maxwell, Assistant Chief, Soils Division, WES. Engineers of the WES Soils Division actively concerned with the planning, testing, analyzing, and reporting phases of this study were Messrs. R. G. Ahlvin, D. N. Brown, and G. M. Hammitt II. This report was prepared by Mr. Hammitt.

Directors of the WES during the conduct of the study and the preparation of this report were COL John R. Oswalt, Jr., CE, and COL Levi A. Brown, CE. Technical Directors were Mr. J. B. Tiffany and Mr. F. R. Brown.

Contents

Conversion Factors, British to Metric Units of Measurement

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
square inches	6.4516	square centimeters
pounds	0.45359237	kilograms
tons	907.185	kilograms
kips	453.59237	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
miles per hour	1.609344	kilometers per hour

Summary

This report describes a method for rapidly determining the soil strength at forward-area airfields. Through the use of dimensionless ground mobility parameters developed by the U. S. Army Engineer Waterways Experiment Station, soil strength indications are determined by measuring rut depths created by traffic of standard military ground vehicles. This method enables reasonably accurate assessment of soil strength by personnel without special training and without the use of special instruments. If the soil strength existing in the forward areas is known, predictions can be made concerning the ability of a particular site to sustain specific aircraft traffic.

Initially, an office study was conducted that established the potential of such a method. Then limited field verification tests were conducted with four standard military ground vehicles, i.e. a 1/4-ton M151, a 3/4-ton M37, a 2-1/2-ton M35A1, and a 5-ton M55, operated on a prepared unsurfaced heavy clay subgrade with a strength of approximately 2 CBR. First-pass rut depths were measured for each vehicle operated empty and for all but the M55 with maximum cross-country loading.

The results of this testing indicated the feasibility of predicting soil strength based on one-pass rut depth caused by military ground vehicles. This method can be used to predict the ability of a particular forward-area airfield to sustain specific small aircraft traffic. It is recommended that further studies include operations of aircraft from actual landing sites on both clay and sand.

EVALUATION OF SOIL STRENGTH OF UNSURFACED FORWARD-AREA AIRFIELDS BY USE OF GROUND VEHICLES

Introduction

Background

1. Recommended soil strength criteria for airfields in the theater of operations are presented in Department of the Army Technical Manual 5-330.[1] These criteria are in the form of design curves for paved and unpaved soil surfaces. The design curves are based on the CBR test for soil strength. Evaluation of soil strength by the CBR test requires trained personnel, special test equipment, certain laboratory facilities, and an amount of time that is dependent on the scope of the survey. The time, however, can be reduced significantly through use of the cone penetrometer. Reference 1 provides for use of the cone penetrometer as an expedient in lieu of the CBR test, thus eliminating the need for laboratory facilities and reducing the equipment and time requirements. However, the cone penetrometer test still requires special equipment and a minimum amount of training for the tester. Therefore, there is a critical need for a method by which a reasonably accurate assessment of soil strength can be rapidly made without the use of any special instruments by personnel without special training, particularly to aid in the selection of forward-area airfield sites to be used for short periods of time.

Objective and scope of study

2. Objective. The objective of this study was to establish a method of rapidly assessing initial soil strength or changes in soil strength at existing fields as a result of rainfall. This method would be used in connection with selection of sites for forward-area airfields and would eliminate requirements for specially trained personnel, special test equipment, and laboratory facilities. Rapid survey of entire landing strip areas would be possible with less effort involved than that involved in surveys using the cone penetrometer or CBR method.

3. Scope. The initial program consisted of using existing research data to make certain predictions as to the ability of a particular site to

sustain specific aircraft traffic. This program produced results relating the operation of several standard military ground vehicles to requirements for operation of military aircraft on unsurfaced fields. These results were tabulated as the final product of the office study, but because of certain areas in which inadequate correlative data existed, elements of engineering judgment were involved in the tabulation. Thus, a field test effort was made to validate the reliability of the initial scheme or to provide a basis for its adjustment to a final satisfactory site assessment system. The field testing consisted of trafficking an existing section at the U. S. Army Engineer Waterways Experiment Station (WES) with four military ground vehicles. The four vehicles consisted of a 1/4-ton* M151 truck, a 3/4-ton M37 truck, a 2-1/2-ton M35A1 truck, and a 5-ton M55 truck. The large-scale test facility allowed the four military ground vehicles to traffic the section at approximately 5 mph. Cross sections and cone index data were taken prior to traffic and after one pass of each vehicle. Rut depth measurements were made at selected points in the tracks at the rear of the test vehicle. Dimensionless ground mobility parameter predictions were compared with the data taken.

4. The tabulated results for application of the method of rapid soil strength determination presented herein are given in Appendix A. This appendix shows the allowable coverages for example aircraft based on one-pass rut depths of four standard military ground vehicles.

Terminology

5. For information and clarity, definitions of certain terms used in this report are given below:

California Bearing Ratio (CBR). A measure of the bearing capacity of the soil based upon its shearing resistance. The CBR is calculated by dividing the unit load required to force a piston into the soil by the unit load required to force the same piston the same depth into a standard sample of crushed stone and multiplying by 100.[2]

Cone Index (CI). The cone index is an index of soil consistency or strength. It is the force required to push a 30-deg right circular cone

* A table of factors for converting British units of measurement to metric units is presented on page vii.

of 0.5-sq-in. base area through the soil at a rate of 72 in. per min.[3]

Airfield Index (AI). The airfield index is an index of soil consistency or strength. It is the force required to push a 30-deg right circular cone of 0.2-sq-in. base area through the soil at a rate of 72 in. per min.[4]

Office Study

Data sources

6. Ground-flotation study. The one-pass rut depth data used for this study were obtained partly from accelerated traffic tests conducted by the WES to establish ground-flotation criteria for the operation of aircraft on unsurfaced soils. Complete information on this test program can be found in reference 5.

7. To establish the desired criteria, test sections were constructed of heavy clay (CH). Classification data for the soils used in test sections are shown in plate 1. A typical test section consisted of several test items, each with a different subgrade strength. Each item was divided into traffic lanes, and traffic tests were conducted on the controlled-strength subgrades with load carts equipped with single- or multiple-wheel assemblies and with a range of tire sizes, wheel loads, and tire inflation pressures. All traffic data were obtained on unsodded test items. As reported previously,[6] sod provides strength benefits of such small magnitude that it represents no practical differential.

8. Model tests. Data from model tests conducted at WES with pneumatic tires in soft soils were also utilized. These model tests were conducted in soil carts. The soils and methods of soil preparation used are described in detail in WES Technical Report No. 3-688.[7] Classification data for the soil are shown in plate 2.

9. Input data. In both investigations described above, soil strength measurements were obtained with the standard in-place CBR apparatus described in reference 2. CBR, water content, and density determinations were made at the surface and at 6- and 12-in. depths in each test item just prior to and at the conclusion of traffic. Deformation measurements indicating the total sinkage from the original ground surface were

also made. For the purpose of this study, only single-wheel, initial-pass data were considered. These data and measurements were used as described later. The dimensionless ground mobility parameters were developed from the tests described in reference 7. However, the validity of the tests described in reference 7 was never verified for the type of study reported herein. That is, the results of the model tests reported in reference 7 were not related to the operation of full-scale vehicles.

Analysis of data

10. Dimensionless ground mobility parameters. To accomplish the objective of this study, the dimensionless ground mobility parameters developed at WES were employed. These parameters consist of clay and sand mobility numbers that reduce the variables of wheel load, soil strength, tire size, and tire deflection into a dimensionless ratio of soil and wheel characteristics in the manners shown below.

Clay mobility number (CMN):

$$CMN = \frac{CIbd}{W} \times \left(\frac{\delta}{h}\right)^{1/2} \tag{1}$$

Sand mobility number (SMN):

$$SMN = \frac{G(bd)^{3/2}}{W} \times \frac{\delta}{h} \tag{2}$$

Sinkage number (SN):

$$SN = z/d \tag{3}$$

where

CI = cone index

b = cross-sectional width of tire, in.

d = outside diameter of tire, in.

W = vertical wheel load, lb

δ = tire deflection (difference between heights of loaded and unloaded sections)

h = tire section height, in.

G = cone index gradient (average increase in CI per inch over a depth equal to the tire width)

z = one-pass rut depth, in.

Some of these terms are illustrated in plate 3.

11. A plot showing the relation of sinkage number to clay mobility number is shown in plate 4. This relation should be used in all site evaluations except those involving a clean, cohesionless, free-draining sand. A plot of the sinkage number versus sand mobility number is also shown in plate 4. A comparison study showed close agreement between the relation of sinkage number and clay mobility number as established by small wheels and light load tests and ground-flotation tests with full-scale wheels and loads (plate 5).

12. The soil-strength variable can be expressed in terms of CBR, CI, or AI (see plate 6). CI can be converted to AI by dividing the CI by 50.

13. Application. As previously stated, the standard military ground vehicles chosen for the study reported herein were the 1/4-ton M151, the 3/4-ton M37, the 2-1/2-ton M34, and the 5-ton M55 trucks. Using the empty and loaded front-wheel loads and tire dimensions, data were calculated for a soil strength versus rut depth curve for each vehicle. The front-wheel loads were used because the ground mobility parameters were developed for front-wheel loading only. The dimensionless ground mobility parameters were employed to reduce the variables of wheel load and tire dimensions and to produce the data presented in table 1 and the plots shown in plates 7-10. Similar plots could be prepared for any pneumatic-tired ground vehicle at any loading. After the front tire one-pass rut depth of a particular military ground vehicle has been measured, the approximate soil strength can be determined from an appropriate plot of cone index versus rut depth. With this strength determination, the feasibility of a given aircraft operating at a site can be predicted (see plate 11).

14. Sample problem: Determine if a C-7A aircraft having a single-wheel load of 6.4 kips and tire inflation pressure of 39 psi can successfully operate on a clay site where a 1-in. rut depth resulted from one pass of the front wheel of a 2-1/2-ton M34 cargo truck.

Solution: The empty M34 cargo truck has a front axle weight of

6900 lb and an 11.00x20 tire size. With a one-pass rut depth of 1 in., the sinkage number z/d for this vehicle would be 0.023. From plate 4, the clay mobility number is 5.60. By substitution in equation 1 as shown below, the strength of the soil in terms of CI would be 93.

$$5.6 = \frac{CI \times 12.04 \times 43.2}{3450} \times 0.16^{1/2}$$

$$5.6 = \frac{520.1\ CI}{3450} \times 0.4$$

$$5.6 = 0.06\ CI$$

$$CI = 93;\ AI = 1.9$$

Next, by entering the nomograph (plate 11) with the C-7A load of 6.4 kips and tire pressure of 39 psi and the soil strength (1.9 AI), it is determined that the C-7A cannot successfully operate on this particular landing site.

Validation Tests

15. The results of the office study indicated the potential use of the dimensional analysis technique in predicting soil strength from rut depths and it was decided to validate this conclusion by a limited field study.

Field tests

16. Test section. The field traffic tests were conducted at WES on a special test section constructed under shelter. A general view of the test section prior to traffic is shown in photograph 1. The test bin was approximately 12 ft wide, 170 ft long, and 5 ft deep. The heavy clay soil was placed in the 5-ft-deep test bin in 6-in. lifts. Compaction was performed with a self-propelled pneumatic-tired roller loaded to approximately 30,000 lb. The soil had a liquid limit of 58 and a plasticity index of 31 and was classified as clay (CH). The gradation curve for the heavy clay soil is shown in plate 1. The clay was identical with that used to provide

the input data for the predictions made in the office study. A summary of strength data for the surface of the section before traffic is given in table 2.

17. Test loads and vehicles. One-pass traffic was applied to the test section with the vehicles described in the following tabulation:

Vehicle	Weight lb
1/4-ton M151	
Empty	2,635
Max cross-country load	3,035
3/4-ton M37	
Empty	6,010
Max cross-country load	7,820
2-1/2-ton M35A1	
Empty	13,500
Max cross-country load	18,500
5-ton M55	20,500

All vehicles were operated at approximately 5 mph. The vehicle characteristics are documented in Ordnance Tank Automotive Command, Section S..V-1 dated January 1967.[8] All trucks used the tire size and pressure recommended by the Ordnance Tank Automotive Command. Weights were approximately the same as those recommended by the manufacturer. All computations were based on manufacturer's values listed in table 1.

Test and test results

18. A summary of the test data, including soil strength (CI and CBR) and rut depth, is presented in table 2. Cross sections of the test section at different stations prior to traffic are shown in plete 12. The M51, M37, and M35A1 each made one pass down the test section empty. The three vehicles then made one pass with the maximum cross-country load. The M55 trafficked the section at a weight of 20,500 lb. Each vehicle was positioned to traffic fresh soil each time.

19. Operation 1. The empty 1/4-ton M151 (weight 2635 lb) traversed the prepared test section. Cross sections after one pass are shown in plate 12. Photograph 2 shows the section after one pass of the empty M151 vehicle. The rut depth measured an average of 0.10 in. excluding upheaval and 0.11 in. including upheaval.

20. <u>Operation 2.</u> An empty M37 truck (weight 6010 lb) trafficked the test section next. Cross sections after one pass are shown in plate 12. Photograph 3 shows the section after one pass of the empty M37 vehicle. The rut depth measured an average of 0.43 in. excluding upheaval and 0.55 in. including upheaval.

21. <u>Operation 3.</u> An empty 2-1/2-ton M35A1 vehicle (weight 13,500 lb) trafficked the test section next. Cross sections after one pass are shown in plate 12. Photograph 4 shows the section after one pass of the M35A1. The rut depth measured an average of 0.51 in. excluding upheaval and 0.96 in. including upheaval. The test section was planed to remove ruts. Cross sections after planing are shown in plate 13.

22. <u>Operation 4.</u> A loaded 1/4-ton M151 vehicle with a weight of 3035 lb trafficked the test section. Photograph 5a shows the test section after one pass of the loaded M151. The rut depth measured an average of 0.16 in. excluding upheaval and 0.28 in. including upheaval. Cross sections at various stations are shown in plate 13.

23. <u>Operation 5.</u> Next, a 3/4-ton M37 vehicle with a gross weight of 7800 lb trafficked the test section. Photograph 5b shows the test section after one pass of the loaded M37, and cross sections are shown in plate 13. The rut depth measured an average of 0.60 in. excluding upheaval and 1.09 in. including upheaval.

24. <u>Operation 6.</u> A 5-ton M55 vehicle with a gross weight of 20,500 lb trafficked the test section next. Photograph 5c shows the test section after one pass of the empty M55 vehicle. The rut depth measured an average of 0.57 in. excluding upheaval and 1.34 in. including upheaval. The test section was planed to remove ruts. The cross sections after one pass of the empty M55 vehicle are shown in plate 13.

25. <u>Operation 7.</u> Next, a 2-1/2-ton M35A1 vehicle with a gross weight of 18,500 lb trafficked the test section. Photograph 5d shows the test section after one pass of the loaded M35A1 vehicle. The rut depth measured an average of 1.0 in. excluding upheaval and 1.86 in. including upheaval.

26. After completion of testing, CBR's at sta 10+00 and 25+00 were 1.8 and 2.0, respectively.

Comparison of office study
results with field results

27. Table 2 shows a comparison of the predicted and measured rut depths. These data indicate that the rut depths in the clay soil were predicted with a remarkable degree of accuracy.

Conclusions and Recommendations

Conclusions

28. The dimensionless ground mobility parameters developed at WES for small towed model tires can be applied with reasonable accuracy to the prediction of soil strength based on one-pass rut depth caused by several standard military ground vehicles.

29. A plot of rut depth versus soil strength can be developed for any pneumatic-tired ground vehicle with any loading.

30. The method presented in this report can be used to predict the ability of a particular forward-area airfield to sustain specific small aircraft traffic. It should be noted, however, that this study was limited to cohesive soils.

Recommendations

31. A study is needed to verify predictions for a sand surface.

32. A field test with specific aircraft and ground vehicles is needed for a minimum of two sites, one sand site and one clay site.

33. Further study is needed to determine if this method or similar methods could be developed to predict rut depth or deflections for various other surfaces.

Literature Cited

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4. Fenwick, W. B., "Description and Application of Airfield Cone Penetrometer," Instruction Report No. 7, Oct 1965, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

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6. Womack, L. M., "Traffic Tests to Determine the Benefits of Vegetation in Increasing Traffic Coverages," Miscellaneous Paper No. 4-769, Dec 1965, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

7. Freitag, D. R., "A Dimensional Analysis of the Performance of Pneumatic Tires on Soft Soils," Technical Report No. 3-688, Aug 1965, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

8. Headquarters, Department of the Army, "Military Tactical Vehicles (Ordnance Corps Responsibility)," Technical Manual 9-236, Sept 1960, Washington, D. C.

Table 1

Determination of Soil Strength from Rut Depth for a Clay Soil

Vehicle	Vehicle Weight lb	Tire Size	Unloaded Outside Tire Diam (d) in.	Tire Pressure psi	Unloaded Tire Width (b) in.	Rut Depth (z) in.	Sinkage Coefficient z/d	Clay Mobility No.	Cone Index
1/4-ton, 4x4 M151 truck	2,473 Empty with driver	7:00x16	30.5	20	7.17	0	0.0000	>20.00	165
						Trace (0.1)	0.0033	10.00	82
						0.25	0.0082	7.70	63
						0.50	0.0163	6.00	49
						1.0	0.0327	4.00	33
						2.0	0.0657	3.00	24
						3.0	0.0983	2.75	--
	3,000 Driver and 3 passengers					0	0.0000	>20.00	200
						Trace (0.1)	0.0033	10.00	100
						0.25	0.0082	7.70	77
						0.50	0.0163	6.00	60
						1.0	0.0327	4.00	40
						2.0	0.0657	3.00	30
						3.0	0.0983	2.75	--
3/4-ton, 4x4 M37 truck	5,950 Empty	9:00x16	35.2	50	9.63	0	0.0000	>20.00	250
						Trace (0.1)	0.0028	11.00	133
						0.25	0.0071	8.00	97
						0.50	0.0142	6.00	73
						1.0	0.0282	4.25	51
						2.0	0.0568	3.10	38
						4.0	0.1132	2.60	31
	7,820 Gross weight					0	0.0000	>20.00	265
						Trace (0.1)	0.0028	11.00	140
						0.25	0.0071	8.00	102
						0.50	0.0142	6.00	76
						1.0	0.0282	4.25	54
						2.0	0.0568	3.10	40
						4.0	0.1132	2.60	33
2-1/2-ton, 6x6 M34 truck	13,900 Empty	11:00x20	43.2	75	12.04	0	0.0000	>20.00	300
						Trace (0.1)	0.0023	11.50	182
						0.25	0.0057	9.00	142
						0.5	0.0115	6.50	103
						1.0	0.0231	4.75	75
						2.0	0.0462	3.50	55
						4.0	0.0925	2.75	43
						6.0	0.1388	2.50	39
	24,300 Gross weight					0	0.0000	>20.00	350
						Trace (0.1)	0.0023	11.50	218
						0.25	0.0057	9.00	171
						0.5	0.0115	6.50	123
						1.0	0.0231	4.75	90
						2.0	0.0462	3.50	66
						4.0	0.0925	2.75	52
						6.0	0.1388	2.50	--
5-ton, 6x6 M55 truck	24,064 Empty	11:00x20	43.2	75	12.04	0	0.0000	>20.00	400
						Trace (0.1)	0.0023	11.50	249
						0.25	0.0057	9.00	195
						0.50	0.0115	6.50	141
						1.0	0.0231	4.75	103
						2.0	0.0462	3.50	76
						4.0	0.0925	2.75	60
						6.0	0.1388	2.50	54
	34,064 Gross weight					0	0.0000	>20.00	400
						Trace (0.1)	0.0023	11.50	249
						0.25	0.0057	9.00	195
						0.50	0.0115	6.50	141
						1.0	0.0231	4.75	103
						2.0	0.0462	3.50	76
						4.0	0.0925	2.75	60
						6.0	0.1388	2.50	54

Note: All computations made using a δ/h value of 0.16 and based on manufacturer's specified dimensions and weights.

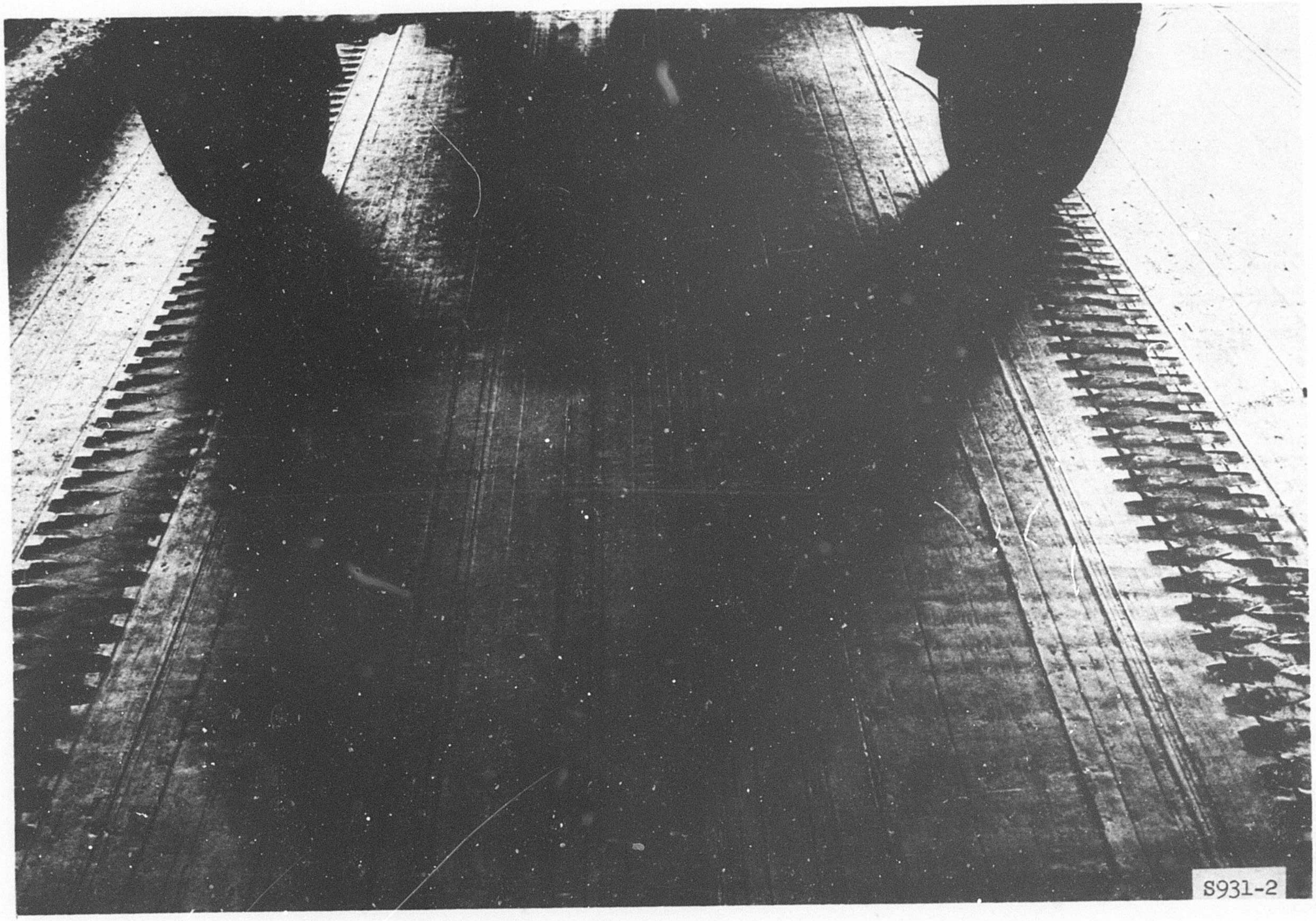
Table 2

Summary of Data

Vehicle Type	Vehicle Load lb	Tire Pressure psi	Tire Size	Strength of Soil Surface CI	Strength of Soil CBR	Sta	Measured Rut Depth, in. From Original Surface	Measured Rut Depth, in. Maximum	Predicted Rut Depth in.
1/4-ton, 4x4 M151 truck	2,635	18 front 22 rear	7:00x16	63	1.8	10+00	0.05	0.05	
				71	1.2	15+00	0.12	0.12	
						20+00	0.10	0.10	
				63	0.8	25+00	0.10	0.10	
						30+00	0.10	0.15	
						35+00	0.10	0.15	
						Avg	0.10	0.11	0.10
	3,035	18 front 22 rear	7:00x16	78		10+00	0.30	0.40	
				78		15+00	0.13	0.20	
				78		20+00	0.05	0.22	
				76		25+00	0.15	0.15	
				66		30+00	0.15	0.45	
						Avg	0.16	0.28	0.22
3/4-ton, 4x4 M37 truck	6,010	40	9:00x16	63		10+00	0.37	0.50	
				72		15+00	0.47	0.50	
						20+00	0.45	0.55	
				63		25+00	0.47	0.50	
						30+00	0.40	0.55	
						35+00	0.40	0.70	
						Avg	0.43	0.55	0.40
	7,800	40	9:00x16	78		10+00	0.70	1.27	
				78		15+00	0.40	0.90	
				78		20+00	0.57	1.10	
				76		25+00	0.70	1.10	
				66		30+00	0.63	1.10	
						Avg	0.60	1.09	0.45
2-1/2-ton, 6x6 M35A1 truck W/W	13,500	35	11:00x20	63		10+00	0.60	1.00	
				72		15+00	0.54	1.00	
						20+00	0.47	0.95	
				63		25+00	0.50	0.80	
						30+00	0.45	1.05	
						Avg	0.51	0.96	1.05 0.90*
	18,500	35	11:00x20	80		12+00	1.12	1.95	
				80		17+00	0.92	1.68	
				72		22+00	0.91	1.83	
				62		27+00	1.05	2.00	
						Avg	1.00	1.86	1.60 1.30*
5-ton, 6x6 M55 truck	20,500	35	11:00x20	78	1.8	10+00	0.65	1.58	
				78		15+00	0.52	1.25	
				78		20+00	0.65	1.50	
				76	2.0	25+00	0.45	1.05	
						Avg	0.57	1.34	1.30

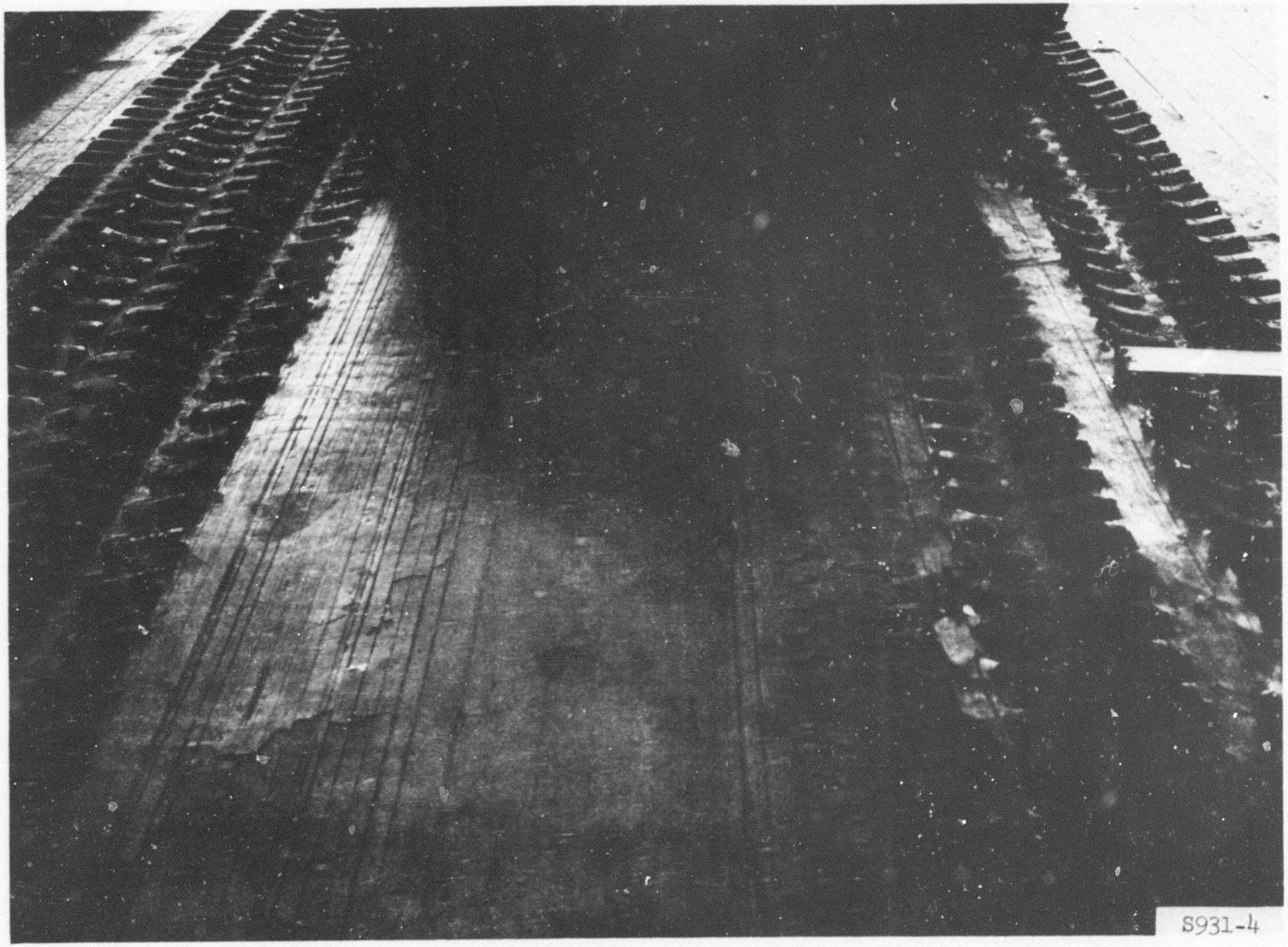
* Predicted rut depth based on pertinent M34 2-1/2-ton vehicle characteristics.

Photograph 1. Test section prior to traffic

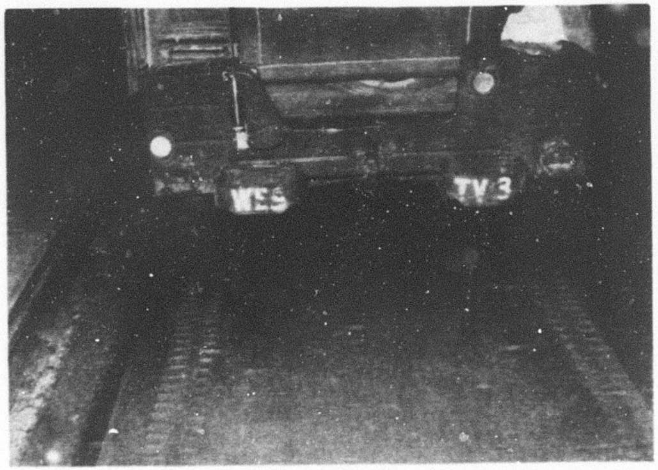


Photograph 2. Ruts resulting from one pass of the empty 1/4-ton M151 truck

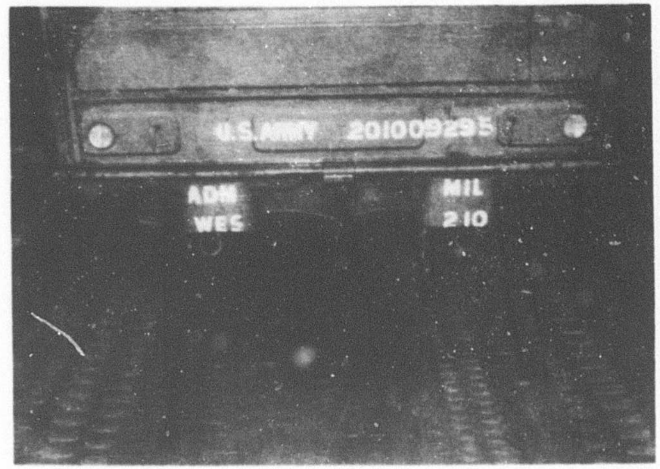
Photograph 3. Rut (at far right) resulting from one pass of the empty 3/4-ton M37 truck



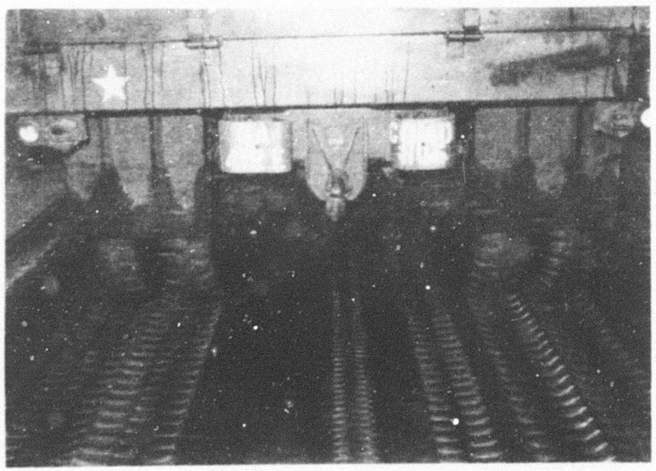
Photograph 4. Ruts resulting from one pass of the empty 2-1/2-ton M35A1 and other vehicles. Rule at right marks print of the rear tire of the M35A1



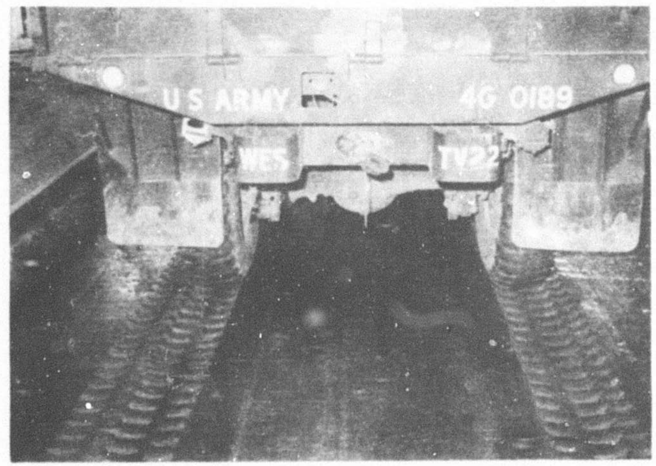
a. Loaded M151



b. Loaded M37



c. Empty M55



d. Loaded M35A1

Photograph 5. Ruts from traffic of various test vehicles. Rut made in untrafficked soil used for analysis

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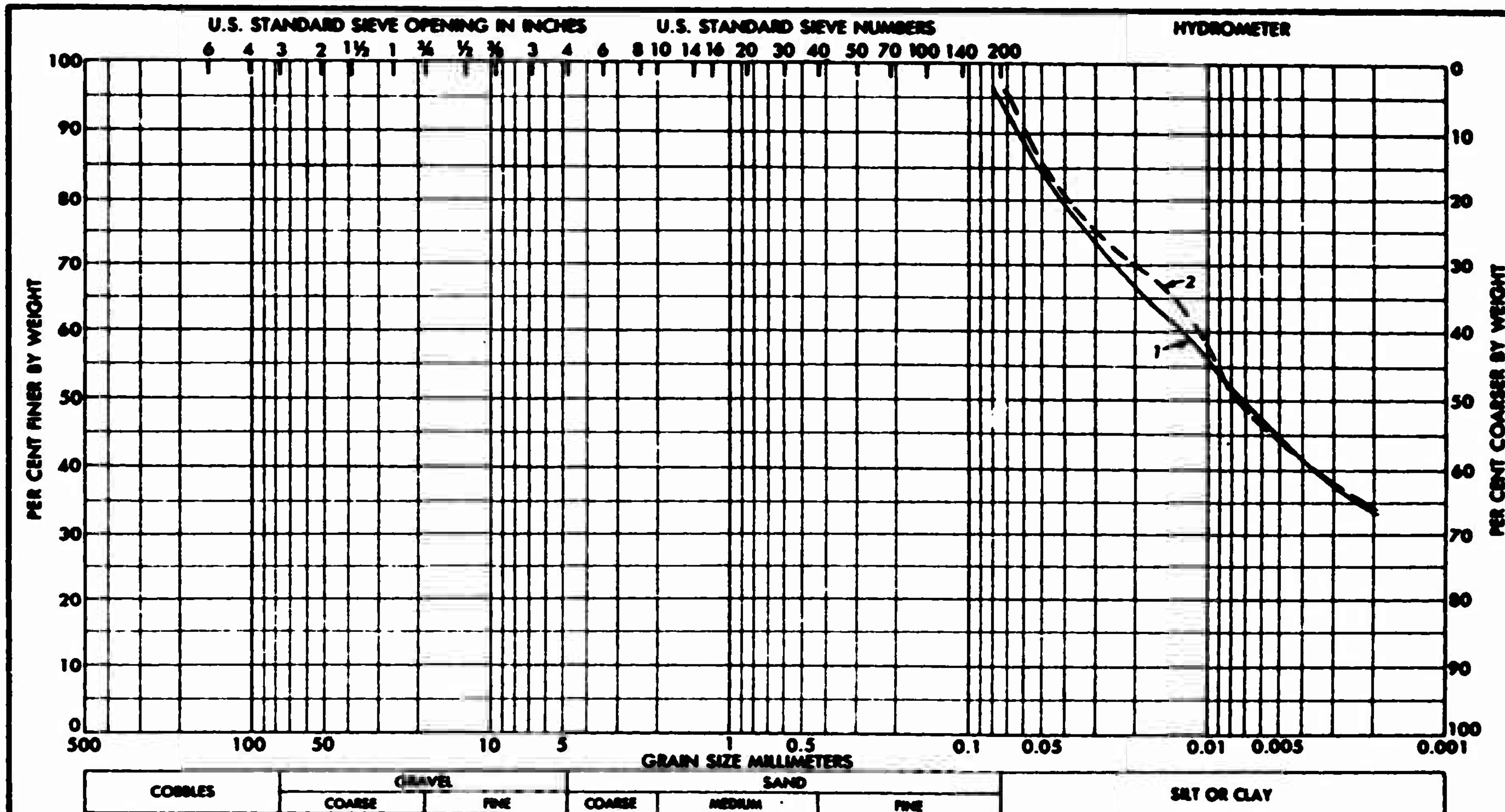


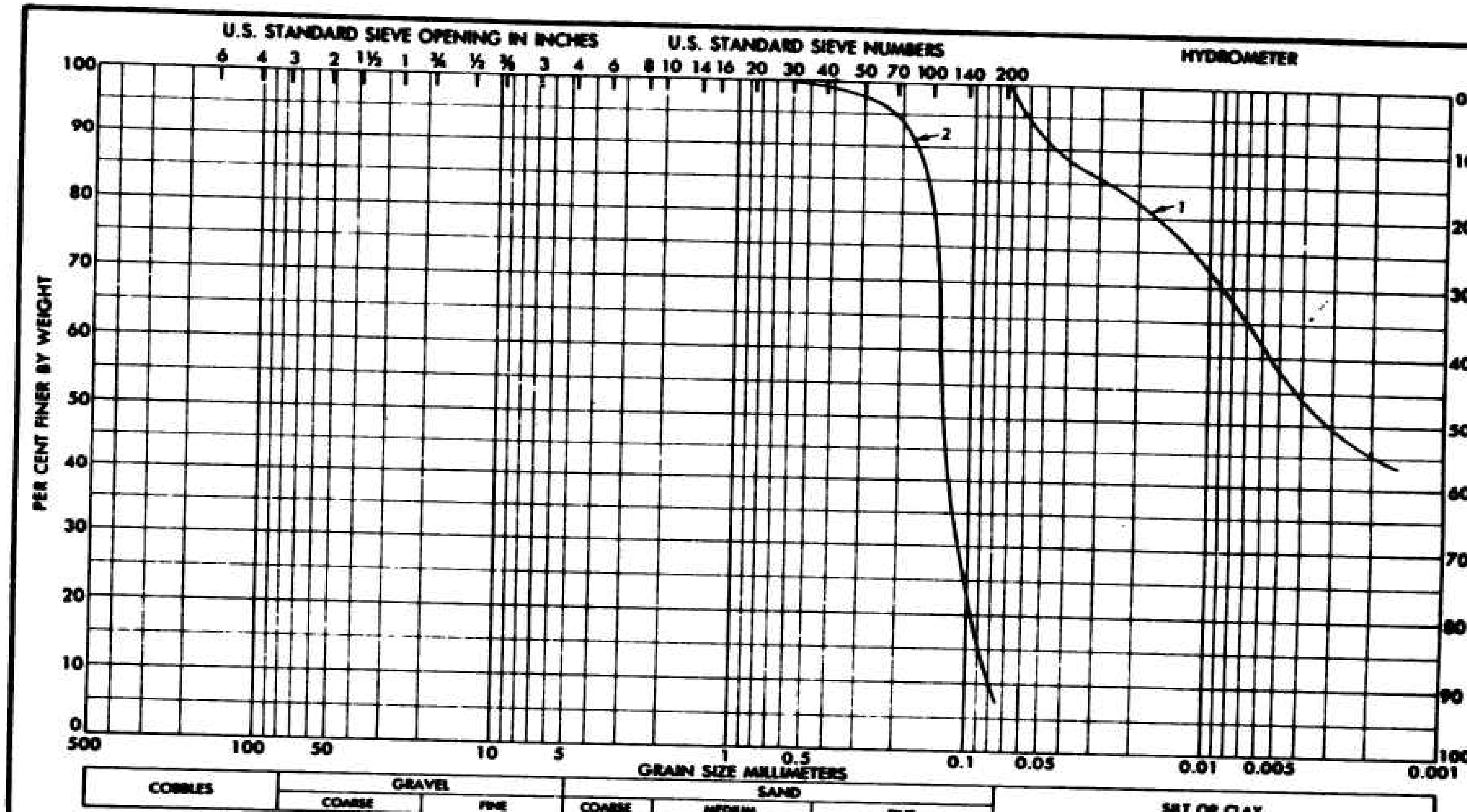
1. TEST SECTIONS 1-4, CLAY (CH), LL = 58, PL = 27, PI = 31
2. ALL OTHER TEST SECTIONS, CLAY (CH), LL = 61, PL = 24, PI = 37

REF 5

SUBGRADE CLASSIFICATION DATA

GROUND-FLOTATION STUDY

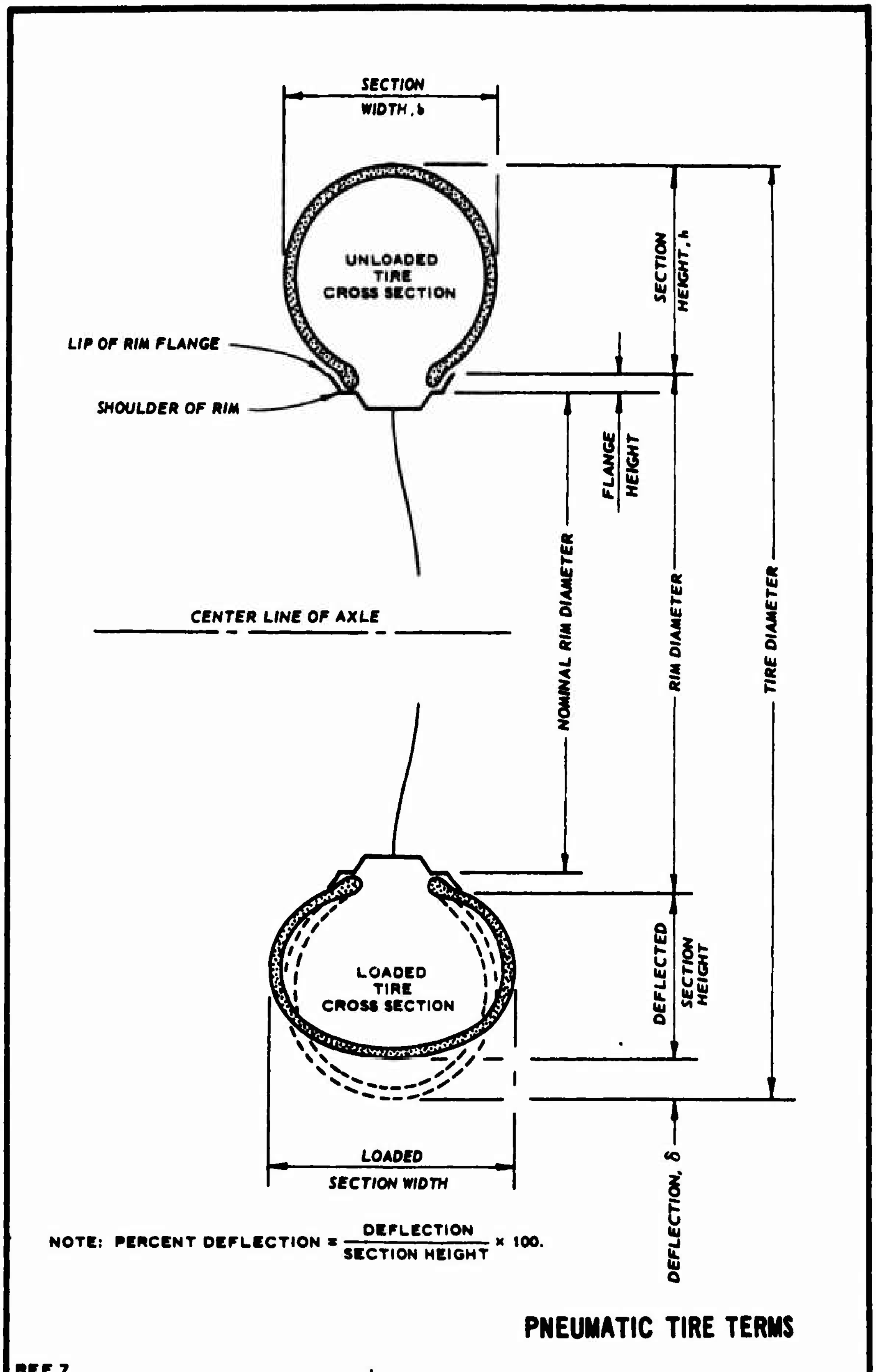
PLATE 2

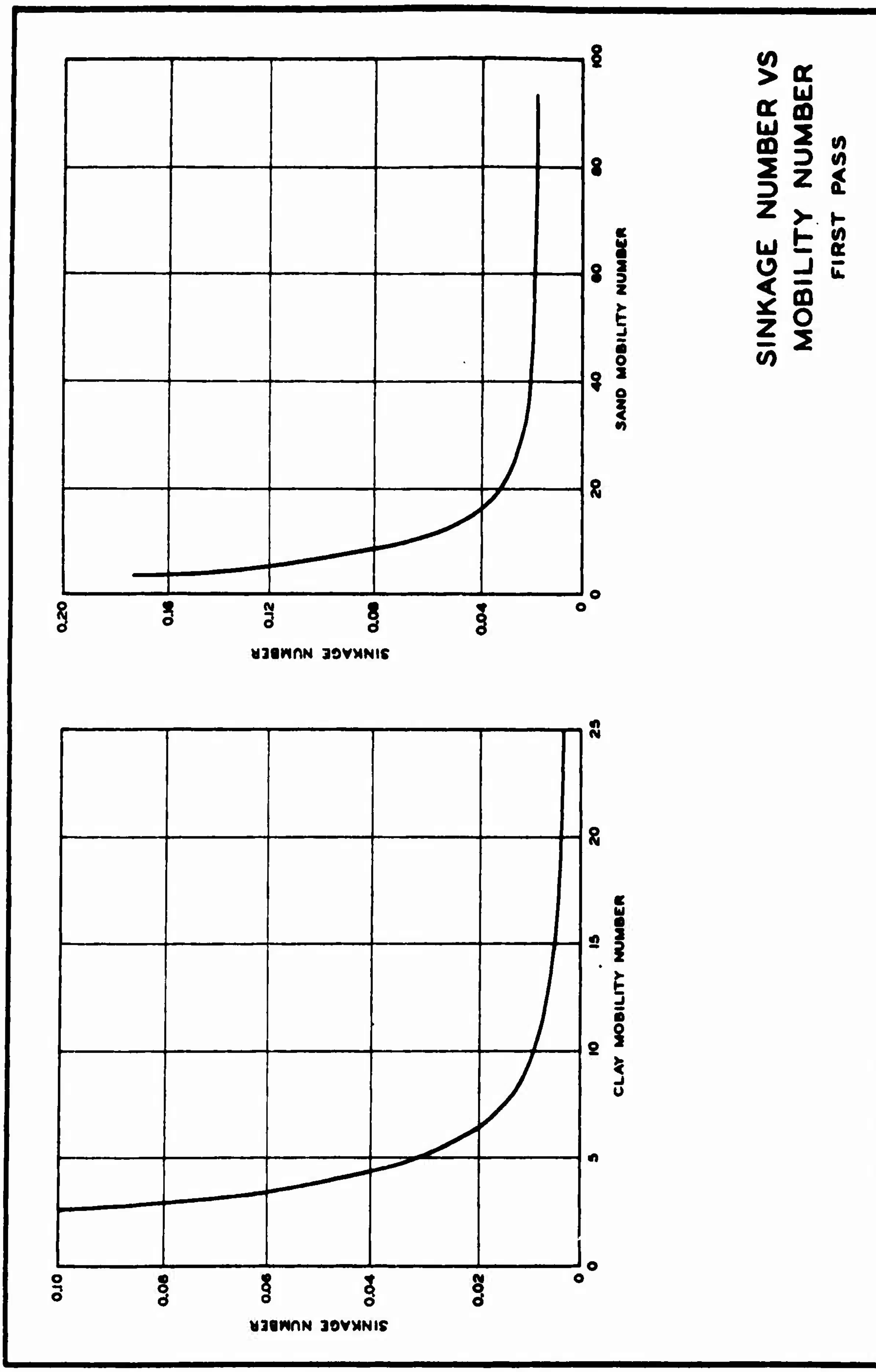


NUMBER	SOIL	MOISTURE	LL	PL	PI	CLASSIFICATION
1	CLAY	VARIOUS	70	25	45	HEAVY CLAY (CH)
*2	SAND	AIR-DRY	–	–	–	FINE SAND (SP-SM)
REF 7						

CLASSIFICATION DATA FOR TEST SOILS

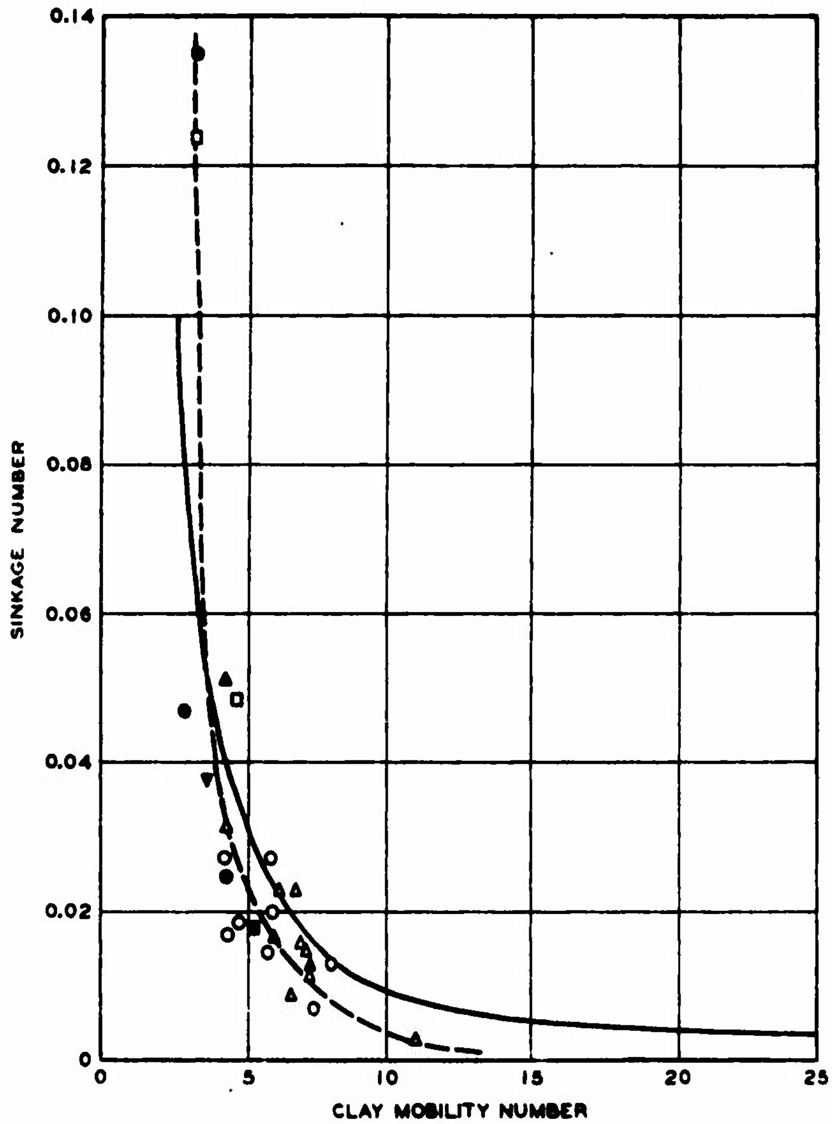
MODEL WHEEL STUDY


SECTION
WIDTH, b
UNLOADED
TIRE
CROSS SECTION
LIP OF RIM FLANGE
SHOULDER OF RIM
SECTION
HEIGHT, h
FLANGE
HEIGHT
CENTER LINE OF AXLE
NOMINAL RIM DIAMETER
RIM DIAMETER
TIRE DIAMETER
LOADED
TIRE
CROSS SECTION
DEFLECTED
SECTION
HEIGHT
LOADED
SECTION WIDTH
DEFLECTION, δ
NOTE: PERCENT DEFLECTION = DEFLECTION / SECTION HEIGHT × 100.
PNEUMATIC TIRE TERMS
REF 7



SINKAGE NUMBER VS
MOBILITY NUMBER
FIRST PASS
SINKAGE NUMBER
SAND MOBILITY NUMBER
0
0.04
0.08
0.12
0.16
0.20
20
40
60
80
100
SINKAGE NUMBER
CLAY MOBILITY NUMBER
0
0.02
0.04
0.06
0.08
0.10
5
10
15
20
25

PLATE 4



LEGEND

- - - - - GROUND-FLOTATION TEST:

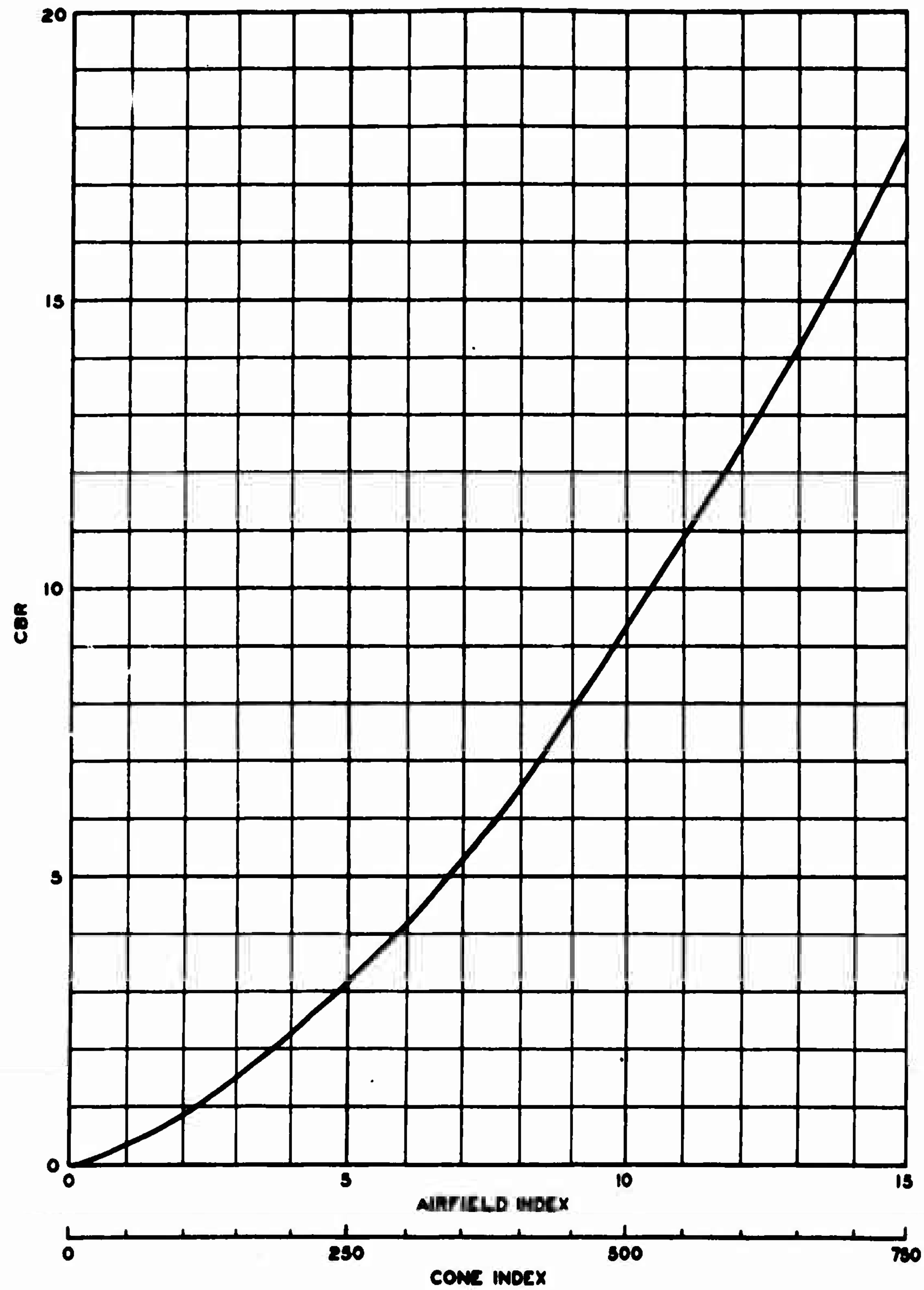
	TIRE SIZE	PLY
O	56-16	24, 32, AND 38
□	30-11.5	24
△	25:00-28	30
■	17:00-16	12
▼	34-99	14
▲	20-20	22
●	30-7.7	18

SINGLE-WHEEL LOADS RANGED FROM 19,000 TO 35,000 LB.

——— AMRB MODEL STUDY

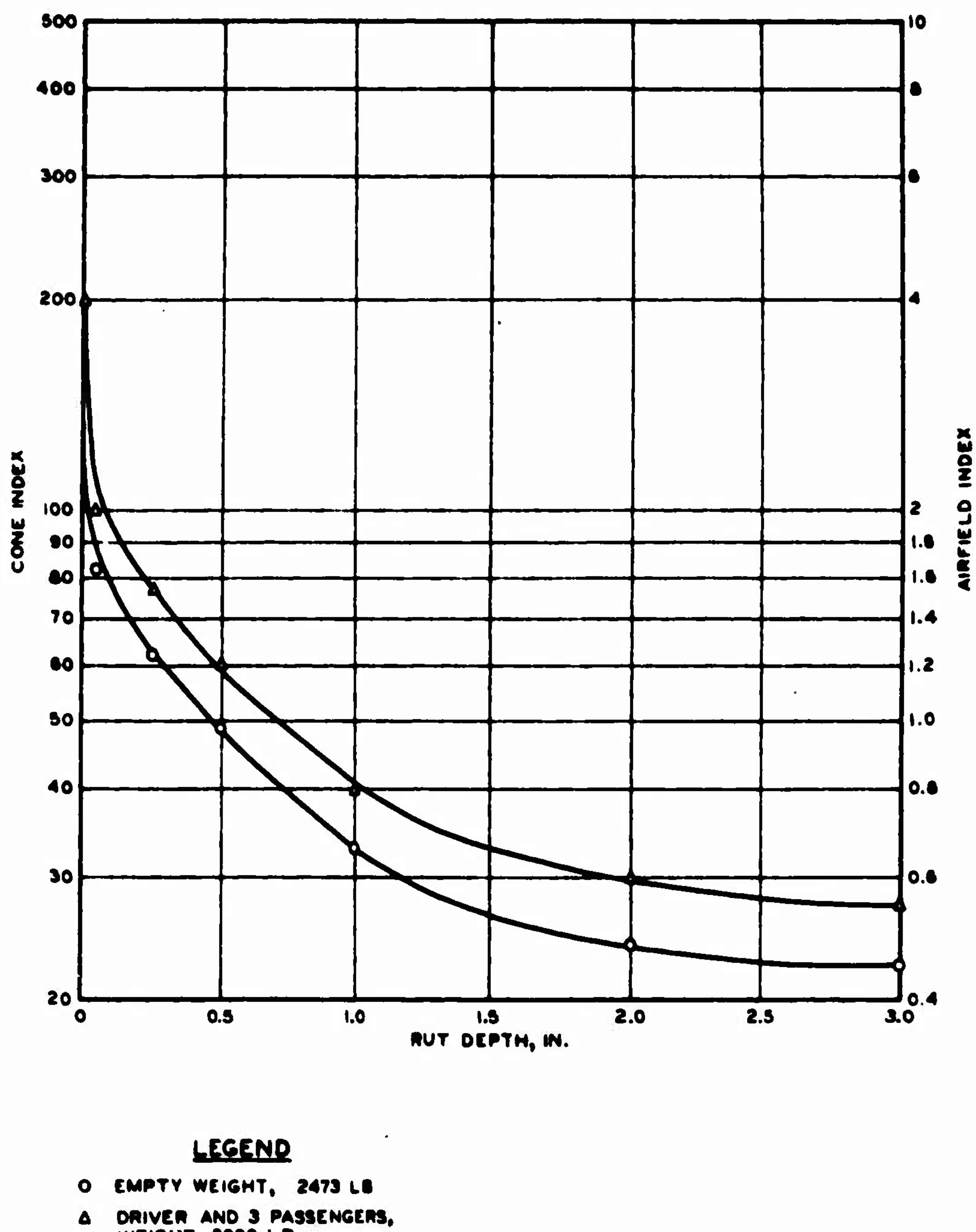
SINKAGE NUMBER VS CLAY MOBILITY NUMBER

COMPARISON STUDY



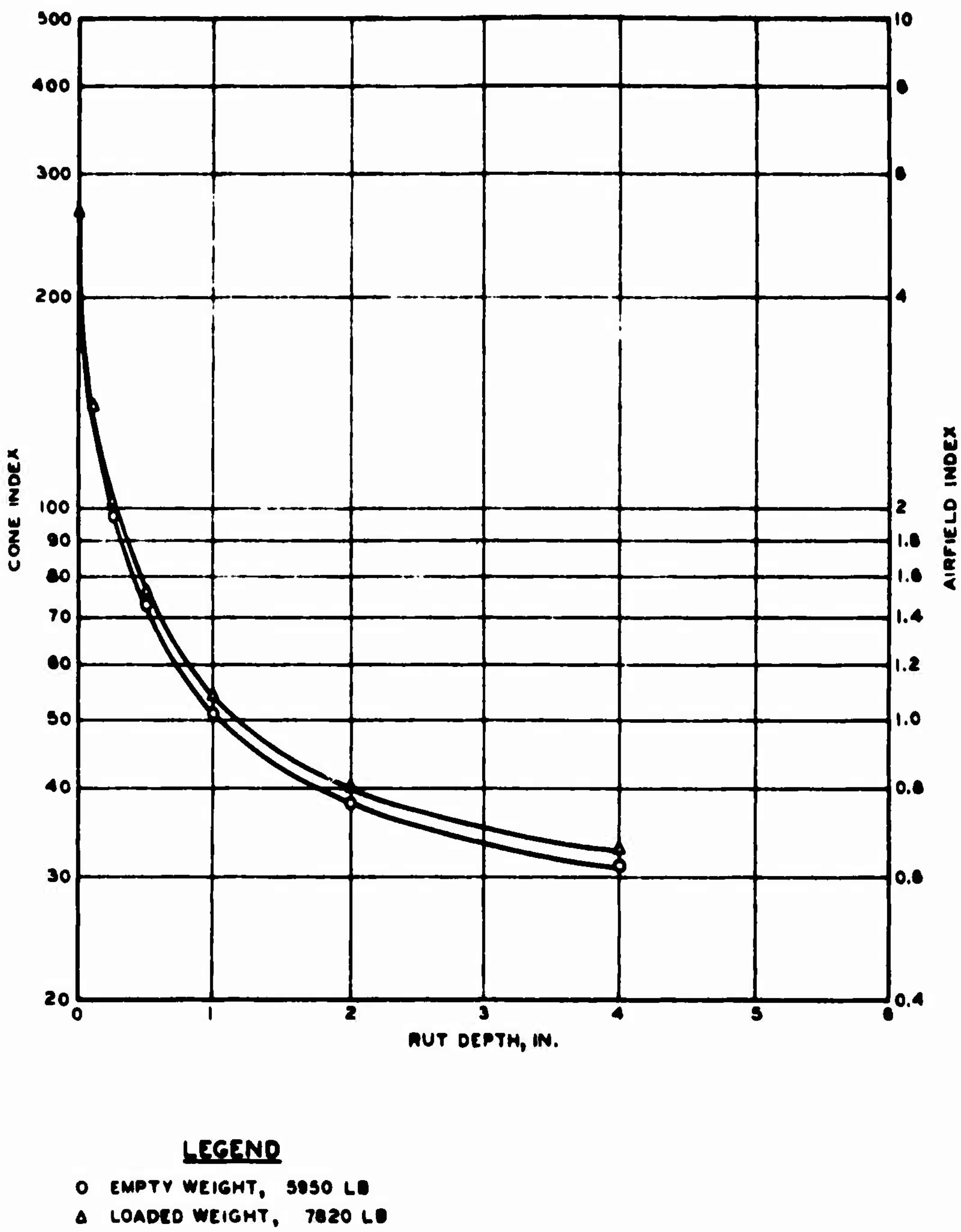
CORRELATION OF CBR
AND AIRFIELD INDEX
OR CONE INDEX

PLATE 6

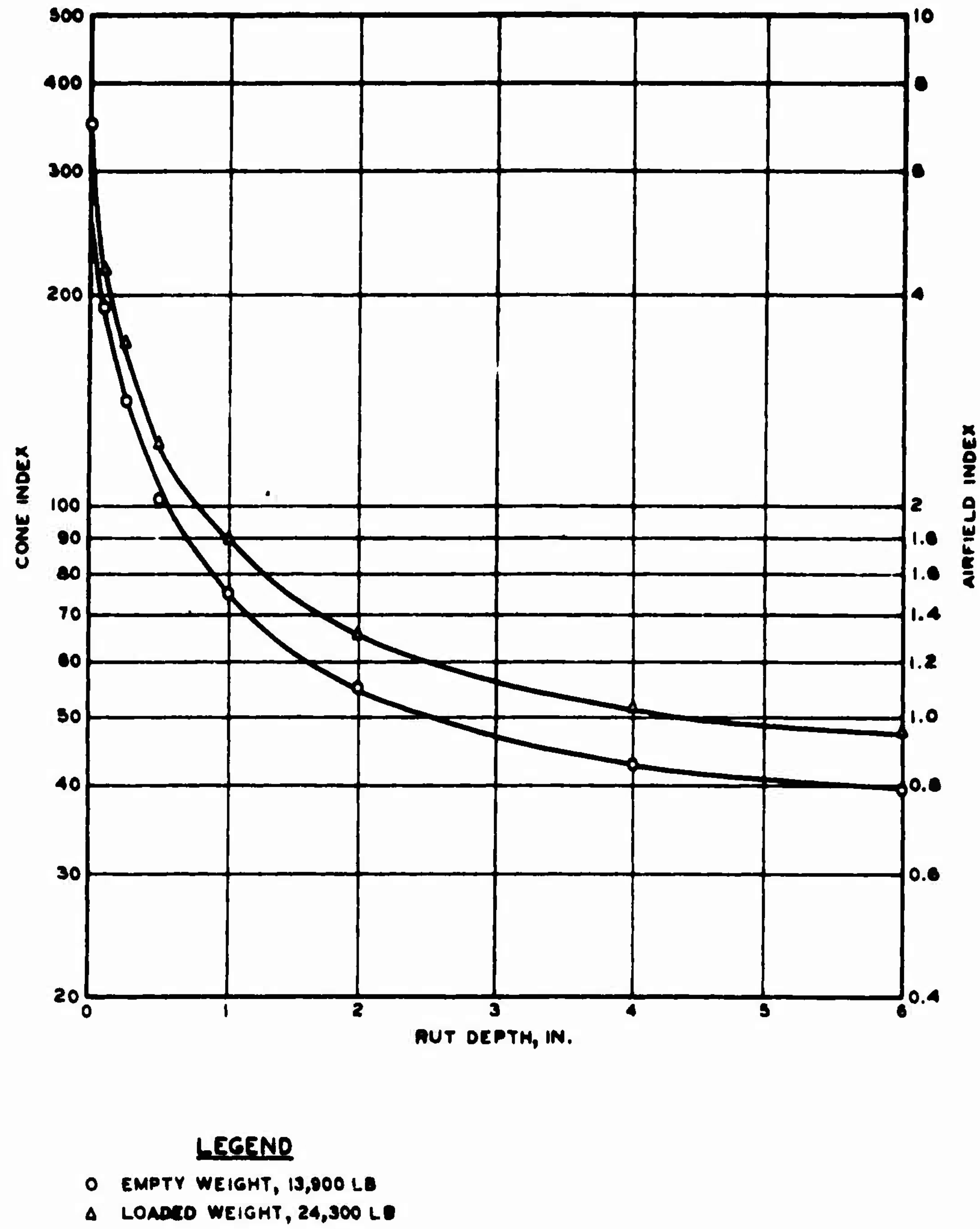


CONE INDEX VS RUT DEPTH

$\frac{1}{4}$-TON, M151 TRUCK

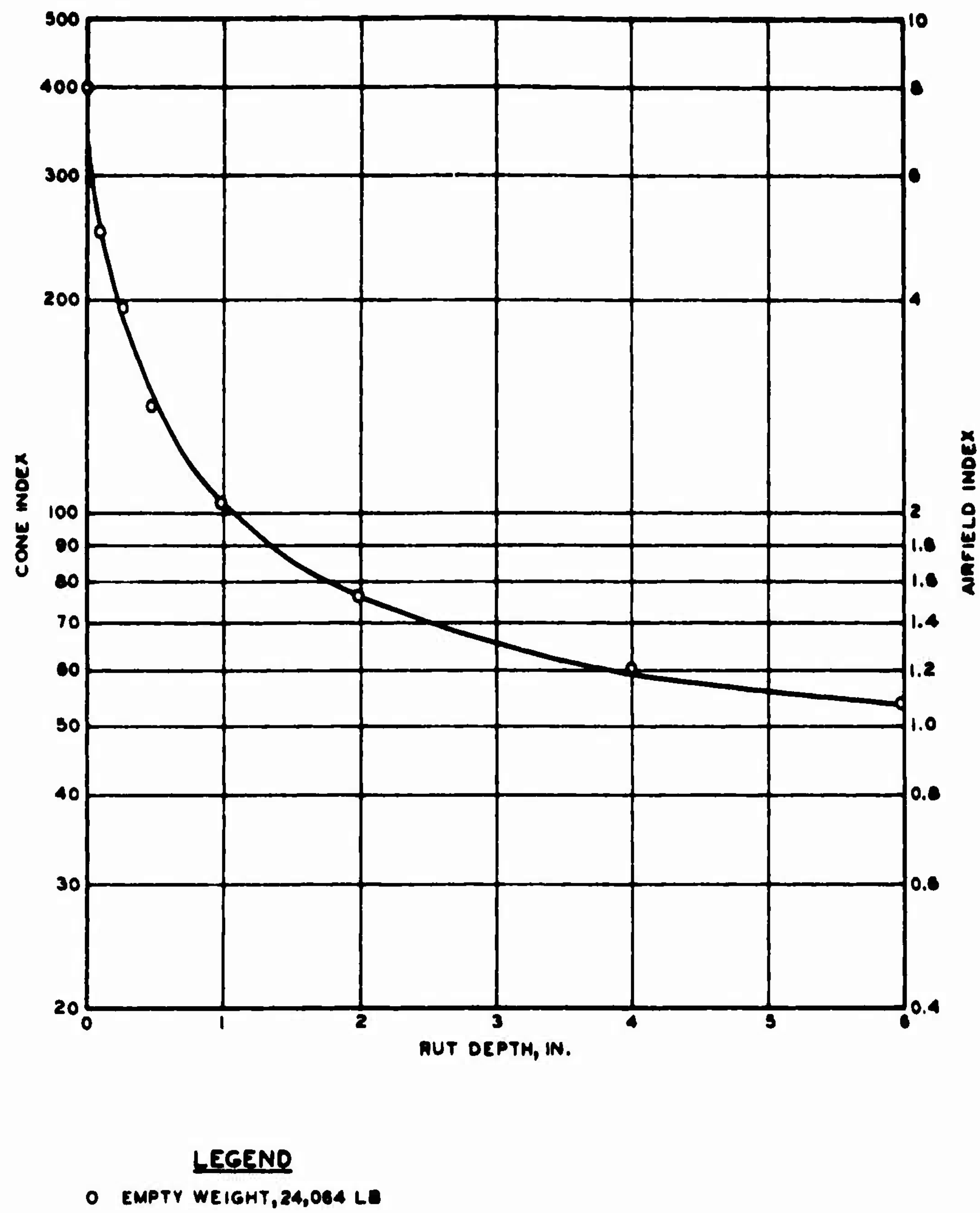


CONE INDEX VS
RUT DEPTH
$\frac{3}{4}$-TON, M37 TRUCK



CONE INDEX VS RUT DEPTH
$2\frac{1}{2}$-TON, M34 TRUCK

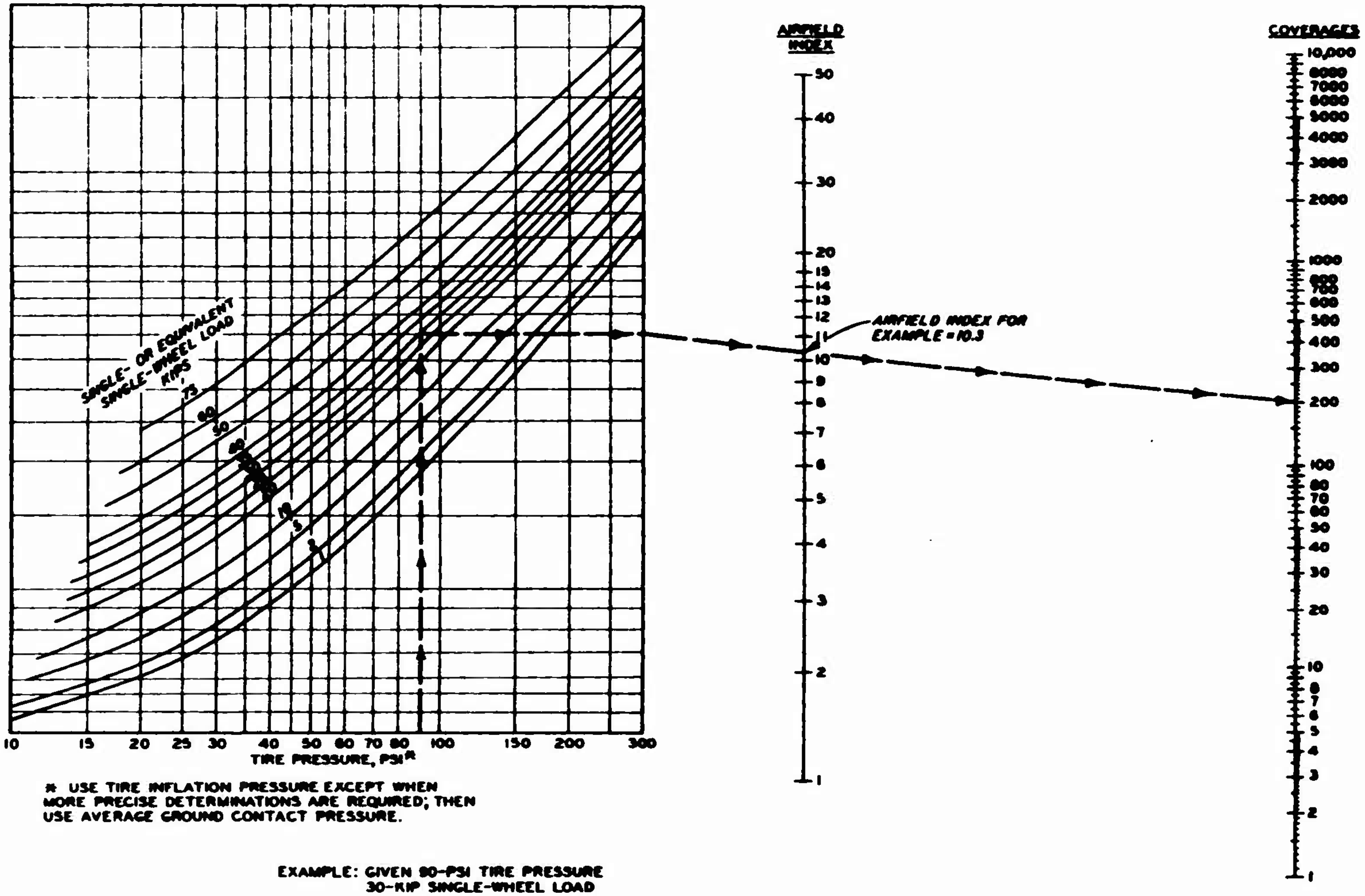
PLATE 9



CONE INDEX VS
RUT DEPTH

5-TON, M55 TRUCK

PLATE 10



* USE TIRE INFLATION PRESSURE EXCEPT WHEN MORE PRECISE DETERMINATIONS ARE REQUIRED; THEN USE AVERAGE GROUND CONTACT PRESSURE.

EXAMPLE: GIVEN 90-PSI TIRE PRESSURE
30-KIP SINGLE-WHEEL LOAD
AIRFIELD INDEX REQUIRED FOR 200 COVERAGES = 10.3

AIRFIELD INDEX REQUIRED FOR OPERATION OF AIRCRAFT ON UNSURFACED SOILS

120587A

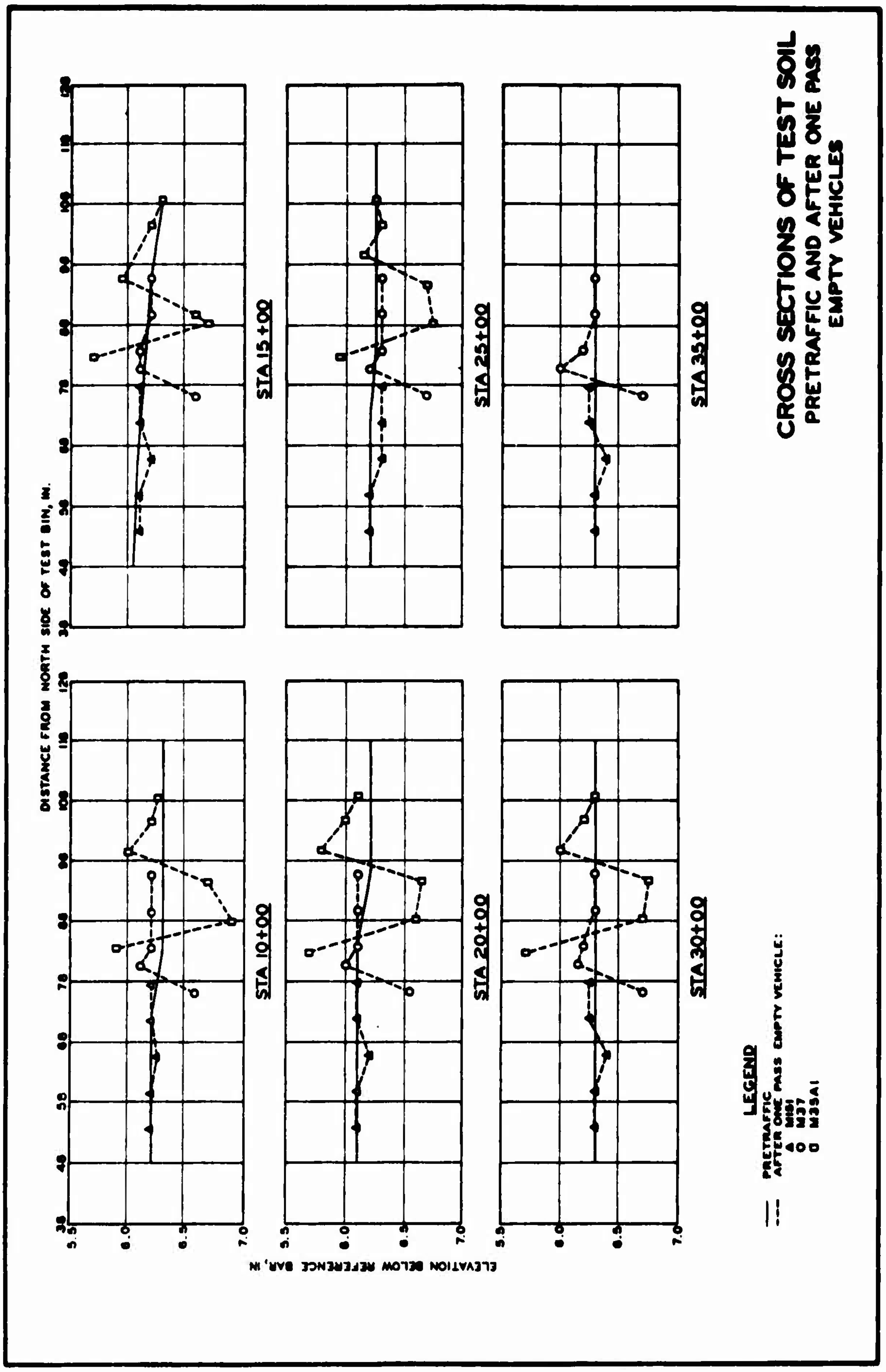
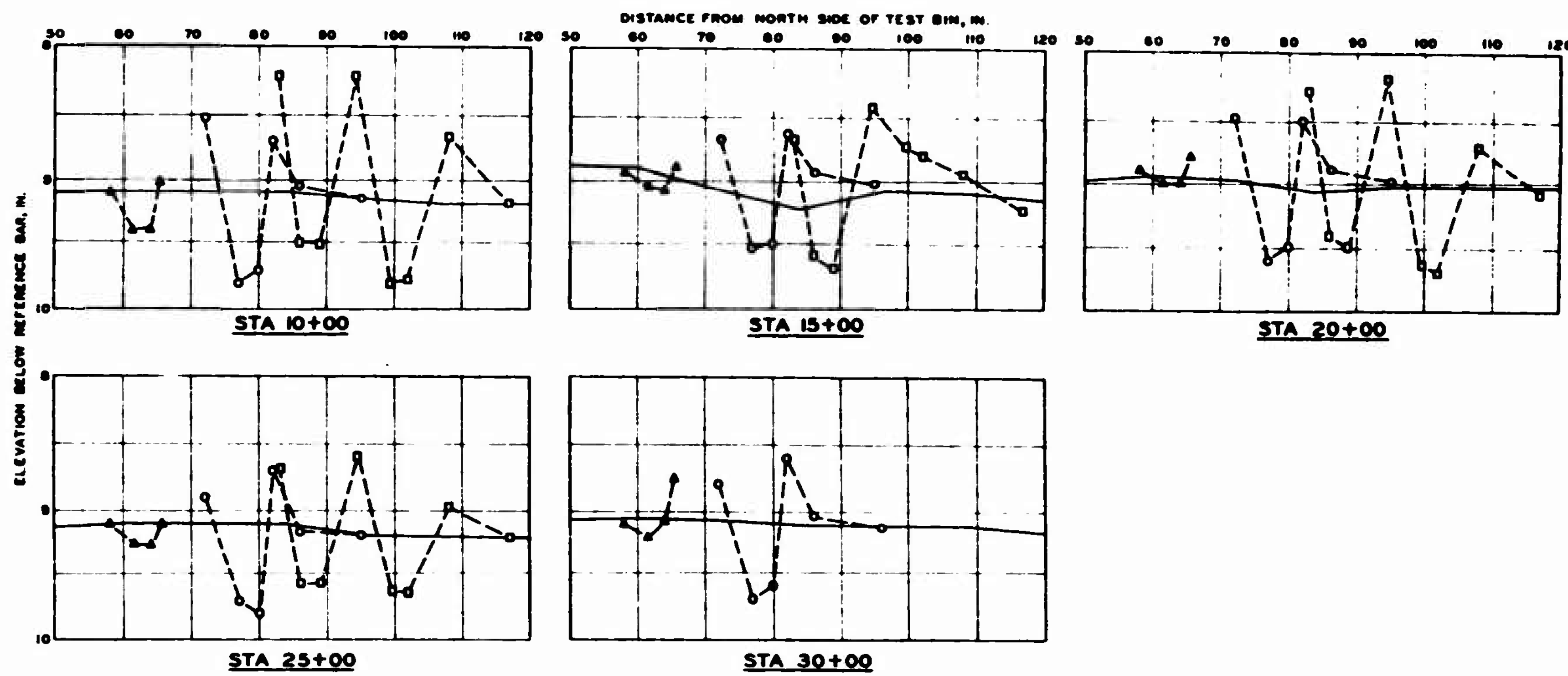

CROSS SECTIONS OF TEST SOIL
PRETRAFFIC AND AFTER ONE PASS
EMPTY VEHICLES
DISTANCE FROM NORTH SIDE OF TEST BIN, IN.
ELEVATION BELOW REFERENCE BAR, IN
STA 10+00
STA 15+00
STA 20+00
STA 25+00
STA 30+00
STA 35+00
LEGEND
PRETRAFFIC
AFTER ONE PASS EMPTY VEHICLE:
M151
M37
M35A1

PLATE 12



LEGEND

— PRETRAFFIC (AFTER 1ST PLANING)
--- AFTER ONE PASS
▲ M51 LOADED
○ M37 LOADED
□ M35 EMPTY

CROSS SECTIONS OF TEST SOIL
PRETRAFFIC AND AFTER ONE PASS
EMPTY AND LOADED VEHICLES

Appendix A: Application of Soil Strength Assessment Method

1. Table A1 relates the results of the operation of several standard military ground vehicles to the requirements for operation of military aircraft on unsurfaced fields. This table was prepared as a general guide in the evaluation of soil strength of unsurfaced forward-area airfields by use of military ground vehicles. A direct evaluation can be made from table A1 by applying one pass of a specific vehicle to an area, measuring the resulting rut depth, then entering the table with the measured rut depth and noting the allowable operations of specific aircraft.

2. This method of rapid soil strength assessment was developed for use on cohesive soils only. However, any rut measurement and corresponding soil strength on a cohesionless soil (sand) would be conservative for use.

3. This method of soil strength determination is meant to be a rapid indication and not a substitute for existing methods. Existing standard methods should be employed when equipment and trained personnel are available.

TABLE A1

STANDARD MILITARY GROUND VEHICLES RELATED TO OPERATION OF MILITARY AIRCRAFT ON UNSURFACED FIELDS

VEHICLE	VEHICLE WEIGHT LB	RUT DEPTH IN.	AIRCRAFT LOADING	AIRCRAFT OPERATIONS	PREDICTED OPERATIONAL CAPABILITY FOR VARIOUS TYPES OF AIRCRAFT*								
					0-1	U-6	U-1A	U-8	C-7A	OV-1		C-123	C-130
1/4-TON, 4x4 M151 TRUCK	2,473 EMPTY	0	EMPTY	1									
				10									
				100									
			FULL LOAD	1									
				10									
				100									
		TRACE 0.1	EMPTY	1									
				10									
				100									
			FULL LOAD	1									
				10									
				100									
		0.25	EMPTY	1									
				10									
				100									
			FULL LOAD	1									
				10									
				100									
	3,000 DRIVER AND 3 PASSENGERS	0	EMPTY	1									
				10									
				100									
			FULL LOAD	1									
				10									
				100									
		TRACE 0.1	EMPTY	1									
				10									
				100									
			FULL LOAD	1									
				10									
				100									
		0.25	EMPTY	1									
				10									
				100									
			FULL LOAD	1									
				10									
				100									

* Aircraft can operate at indicated loading.

Aircraft cannot operate at indicated loading.

Aircraft may be able to operate at indicated loading with calculated risk.

TABLE A1 (Continued)

VEHICLE	VEHICLE WEIGHT LB	RUT DEPTH IN.	AIRCRAFT LOADING	AIRCRAFT OPERATIONS	PREDICTED OPERATIONAL CAPABILITY FOR VARIOUS TYPES OF AIRCRAFT* O-1	U-6	U-1A	U-8	C-7A	OV-1		C-123	C-130
3/4-TON, 4x4 M37 TRUCK	5,950 EMPTY	0	EMPTY	1 10 100									
			FULL LOAD	1 10 100									
		0.1	EMPTY	1 10 100									
		0.1	FULL LOAD	1 10 100									
		0.25	EMPTY	1 10 100									
			FULL LOAD	1 10 100									
	7,800 LOADED	0	EMPTY	1 10 100									
			FULL LOAD	1 10 100									
		TRACE 0.1	EMPTY	1 10 100									
			FULL LOAD	1 10 100									
		0.25	EMPTY	1 10 100									
			FULL LOAD	1 10 100									
		0.50	EMPTY	1 10 100									

* Aircraft can operate at indicated loading.
Aircraft cannot operate at indicated loading.
Aircraft may be able to operate at indicated loading with calculated risk.

TABLE A1 (Continued)

VEHICLE	VEHICLE WEIGHT LB	RUT DEPTH IN.	AIRCRAFT LOADING	AIRCRAFT OPERATIONS	PREDICTED OPERATIONAL CAPABILITY FOR VARIOUS TYPES OF AIRCRAFT*							
					0-1	U-6	U-1A	U-8	C-7A	OV-1	C-123	C-130
2-1/2 TON, 6x6 M34 TRUCK	13,900 EMPTY	0	EMPTY	1								
				10								
				100								
			FULL LOAD	1								
				10								
				100								
		TRACE 0.1	EMPTY	1								
				10								
				100								
			FULL LOAD	1								
				10								
				100								
		0.25	EMPTY	1								
				10								
				100								
			FULL LOAD	1								
				10								
				100								
		0.5	EMPTY	1								
				10								
				100								
			FULL LOAD	1								
				10								
				100								
		1.0	EMPTY	1								
				10								
				100								

* Aircraft can operate at indicated loading.
Aircraft cannot operate at indicated loading.
Aircraft may be able to operate at indicated loading with calculated risk.

TABLE A1 (Continued)

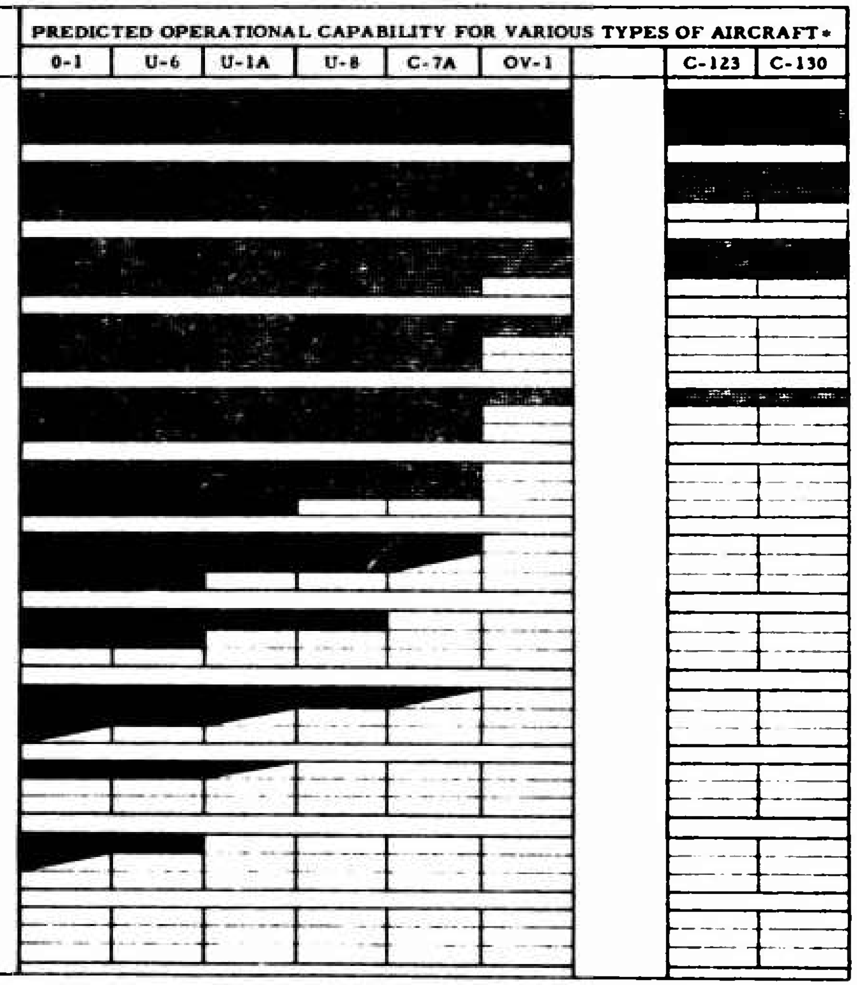
VEHICLE	VEHICLE WEIGHT LB	RUT DEPTH IN.	AIRCRAFT LOADING	AIRCRAFT OPERATIONS	PREDICTED OPERATIONAL CAPABILITY FOR VARIOUS TYPES OF AIRCRAFT* O-1	U-6	U-1A	U-8	C-7A	OV-1		C-123	C-130
2-1/2-TON, 6x6 M34 TRUCK (Continued)	24,300 LOADED	0	EMPTY	1	■	■	■	■	■	■		■	■
				10	■	■	■	■	■	■		■	■
				100	■	■	■	■	■	■		■	■
			FULL LOAD	1	■	■	■	■	■	■		■	■
				10	■	■	■	■	■	■		□	□
				100	■	■	■	■	■	□		□	□
		TRACE 0.1	EMPTY	1	■	■	■	■	■	■		■	■
				10	■	■	■	■	■	◪		■	■
				100	■	■	■	■	■	□		□	□
			FULL LOAD	1	■	■	■	■	■	□		□	□
				10	■	■	■	■	■	□		□	□
				100	■	■	■	■	□	□		□	□
		0.25	EMPTY	1	■	■	■	■	■	■		■	■
				10	■	■	■	■	■	□		□	□
				100	■	■	■	◪	□	□		□	□
			FULL LOAD	1	■	■	■	■	■	□		□	□
				10	■	■	■	■	□	□		□	□
				100	■	■	□	□	□	□		□	□
		0.50	EMPTY	1	■	■	■	■	■	□		□	□
				10	■	■	■	□	□	□		□	□
				100	■	■	□	□	□	□		□	□
			FULL LOAD	1	■	■	■	◪	□	□		□	□
				10	■	■	□	□	□	□		□	□
				100	□	□	□	□	□	□		□	□
		1.0	EMPTY	1	■	■	■	□	□	□		□	□
				10	■	□	□	□	□	□		□	□
				100	□	□	□	□	□	□		□	□
			FULL LOAD	1	□	□	□	□	□	□		□	□
				10	□	□	□	□	□	□		□	□
				100	□	□	□	□	□	□		□	□

* ■ Aircraft can operate at indicated loading.
□ Aircraft cannot operate at indicated loading.
◪ Aircraft may be able to operate at indicated loading with calculated risk.

TABLE A1 (Concluded)

VEHICLE	VEHICLE WEIGHT LB	RUT DEPTH IN.	AIRCRAFT LOADING	AIRCRAFT OPERATIONS
5-Ton, 6x6 M55 TRUCK	24,064	0	EMPTY	1 10 100
			FULL LOAD	1 10 100
		TRACE 0.1	EMPTY	1 10 100
			FULL LOAD	1 10 100
		0.25	EMPTY	1 10 100
			FULL LOAD	1 10 100
		0.50	EMPTY	1 10 100
			FULL LOAD	1 10 100
		1.0	EMPTY	1 10 100
			FULL LOAD	1 10 100
		2.0	EMPTY	1 10 100
			FULL LOAD	1 10 100

PREDICTED OPERATIONAL CAPABILITY FOR VARIOUS TYPES OF AIRCRAFT*



* Aircraft can operate at indicated loading.
Aircraft cannot operate at indicated loading.
Aircraft may be able to operate at indicated loading with calculated risk.

Unclassified

Security Classification

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

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5. AUTHOR(S) (First name, middle initial, last name)

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
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13. ABSTRACT

This report describes a method for rapidly determining the soil strength at forward-area airfields. Through the use of dimensionless ground mobility parameters developed by the U. S. Army Engineer Waterways Experiment Station, soil strength indications are determined by measuring rut depths created by traffic of standard military ground vehicles. This method enables reasonably accurate assessment of soil strength by personnel without special training and without the use of special instruments. If the soil strength existing in the forward areas is known, predictions can be made concerning the ability of a particular site to sustain specific aircraft traffic. Initially, an office study was conducted that established the potential of such a method. Then limited field verification tests were conducted with four standard military ground vehicles, i.e. a 1/4-ton M151, a 3/4-ton M37, a 2-1/2-ton M35A1, and a 5-ton M55, operated on a prepared unsurfaced heavy clay subgrade with a strength of approximately 2 CBR. First-pass rut depths were measured for each vehicle operated empty and for all but the M55 with maximum cross-country loading. The results of this testing indicated the feasibility of predicting soil strength based on one-pass rut depth caused by military ground vehicles. This method can be used to predict the ability of a particular forward-area airfield to sustain specific small aircraft traffic. It is recommended that further studies include operations of aircraft from actual landing sites on both clay and sand.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Airfields						
Military vehicles						
Mobility						
Soil strength						
Unsurfaced airfields						

Unclassified

Security Classification